Probing the effective electron anti-neutrino mass with KATRIN - 

Christoph Wiesinger (TUM) for the KATRIN collaboration, ICHEP, 19.07.2024

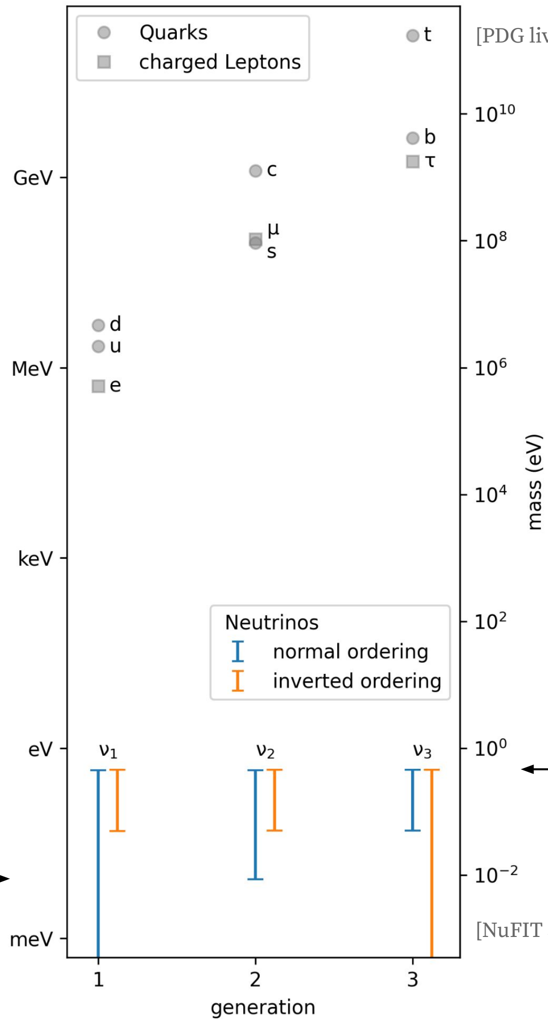
"for the discovery of neutrino oscillations, which shows that

Neutrinos have mass"

[Kajita, McDonald, Nobel Prize in Physics 2015]

- **neutrino oscillations** assess mass squared differences, $\Delta m_{ij}^2 = m_i^2 - m_j^2$

➔ mass mechanism, mass ordering, and **absolute mass** remain **unknown**



[PDG live, pdglive.lbl.gov]

upper bound from **direct measurements**

lower bounds from **oscillation experiments**

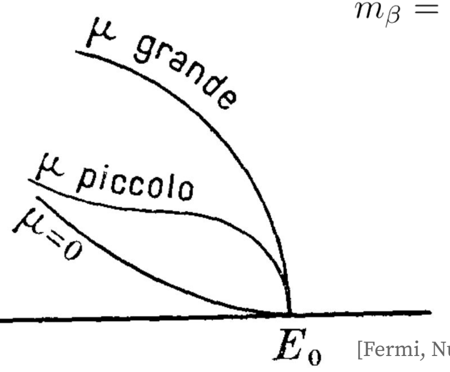
[NuFIT 5.3, nu-fit.org]

β-decay kinematics

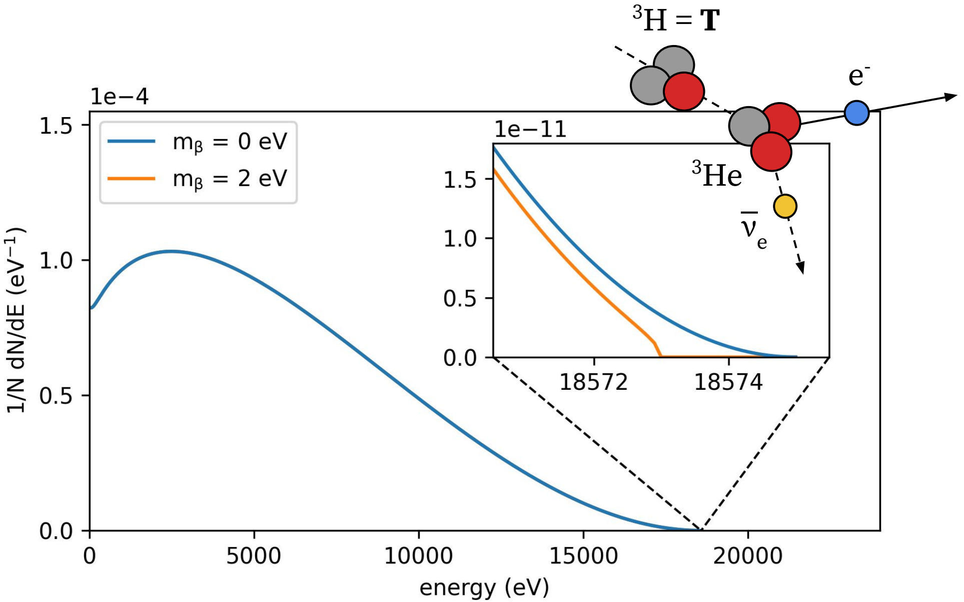
- **direct determination** of phase space modification, **squared neutrino mass**, maximum distortion at endpoint

➔ probe **effective electron anti-neutrino mass**, weighted incoherent sum

$$m_\beta = \sqrt{\sum_i |U_{ei}^2| m_i^2}$$



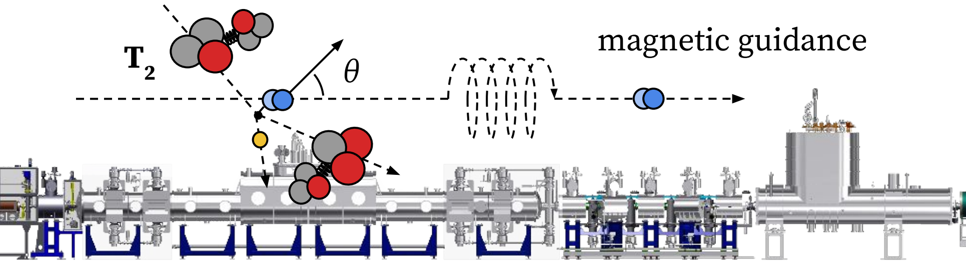
[Fermi, Nuovo Cim. 11 (1934)]

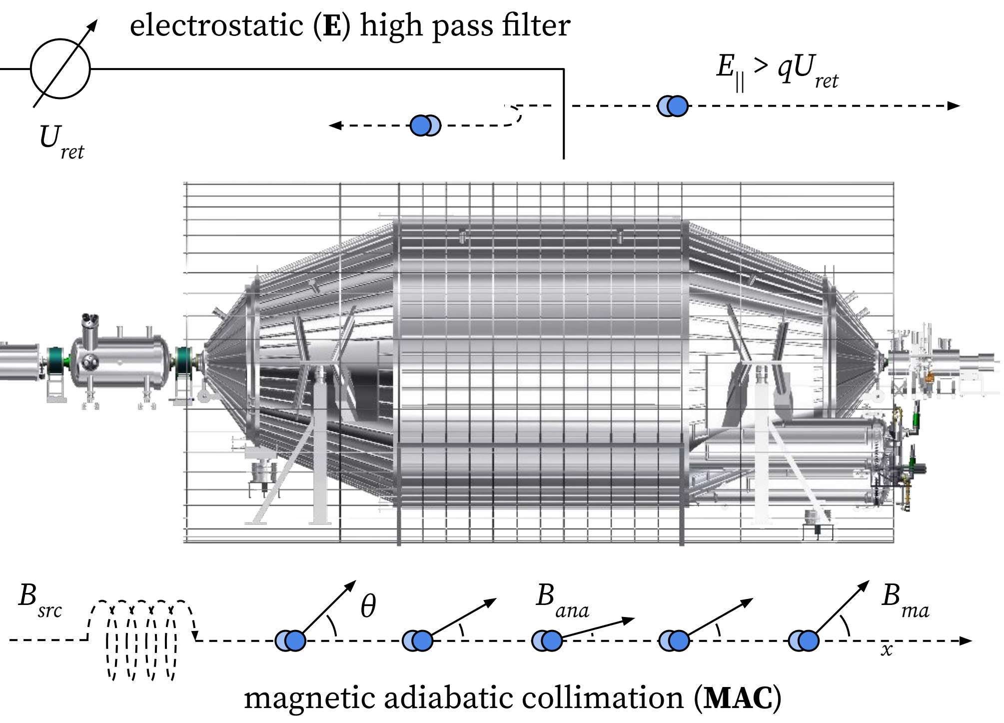



Karlsruhe Tritium Neutrino
(KATRIN) experiment

Working principle

[Aker et al., JINST 16 (2021)]



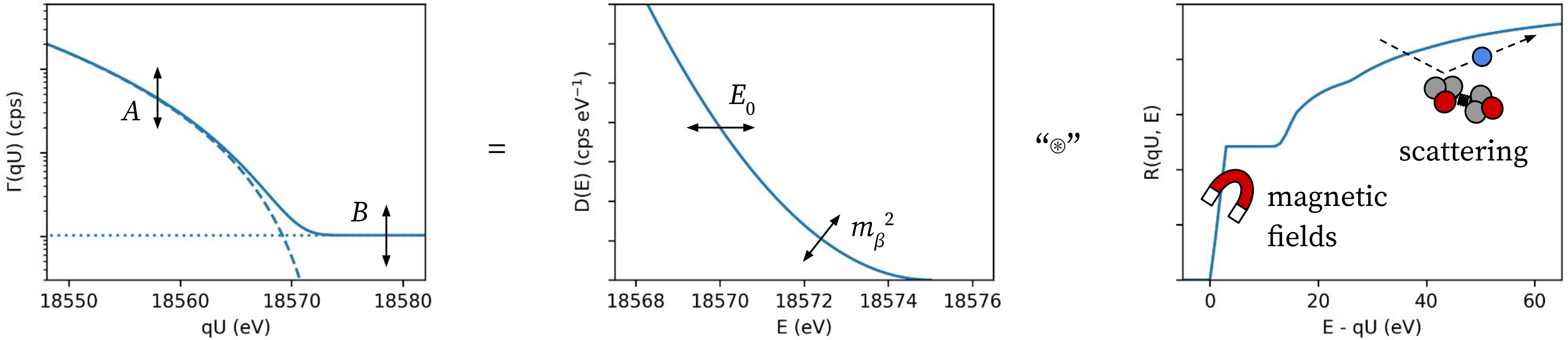


- **high-activity** (~100 GBq) windowless gaseous molecular tritium source, closed loop
- **high-resolution** (~1 eV) **large-acceptance** (0-51°) MAC-E spectrometer system
- **electron counting** at focal plane detector, 148-pixel silicon PIN diode

➔ **integral spectrum** scans, discrete **retarding potential steps**

Analysis strategy

- maximum likelihood fit of **analytical model** $\Gamma(qU) \propto A \int_{qU}^{E_0} D(E; m_\beta^2, E_0)\, R(qU, E)\, \mathrm{d}E + B$

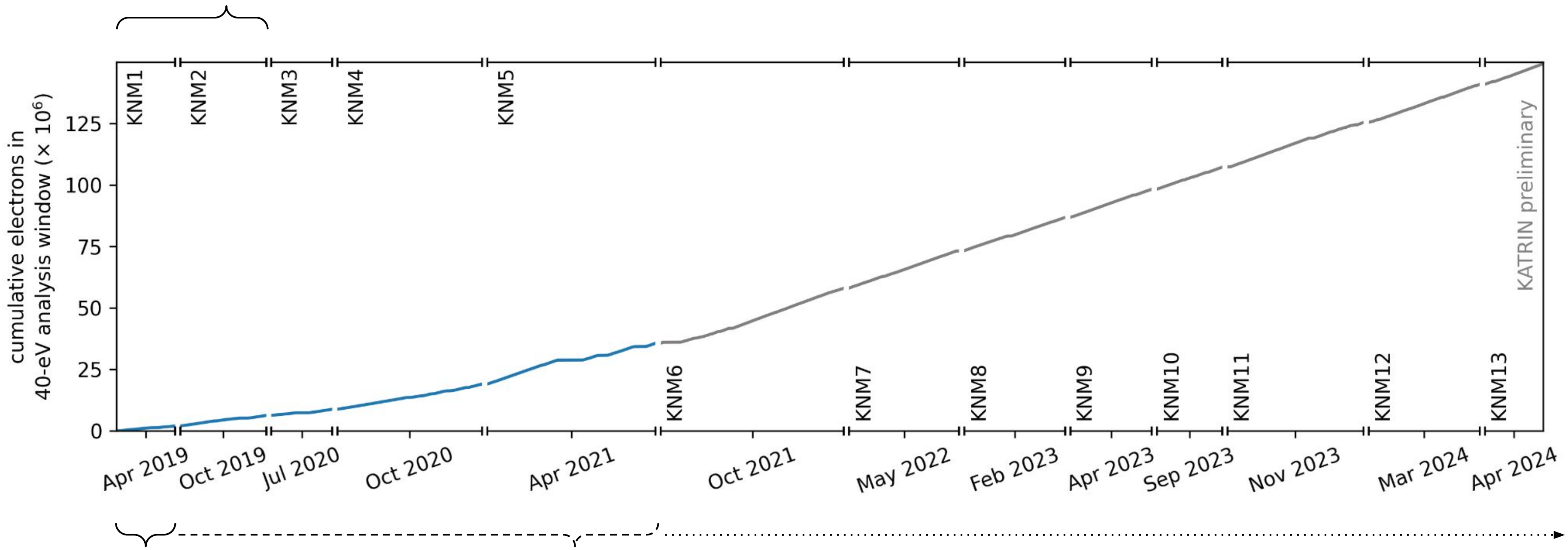


with free **squared neutrino mass** m_β^2, **effective endpoint** E_0, **amplitude** A and **background** B

- **theoretical** and **experimental** inputs, calibration constraints

Data taking overview

second result, $m_\beta < 0.8$ **eV** (90% CL)
[Aker et al., Nature Phys. 18 (2022)]



first result, $m_\beta < 1.1$ **eV** (90% CL)
[Aker et al., PRL 123 (2019)]

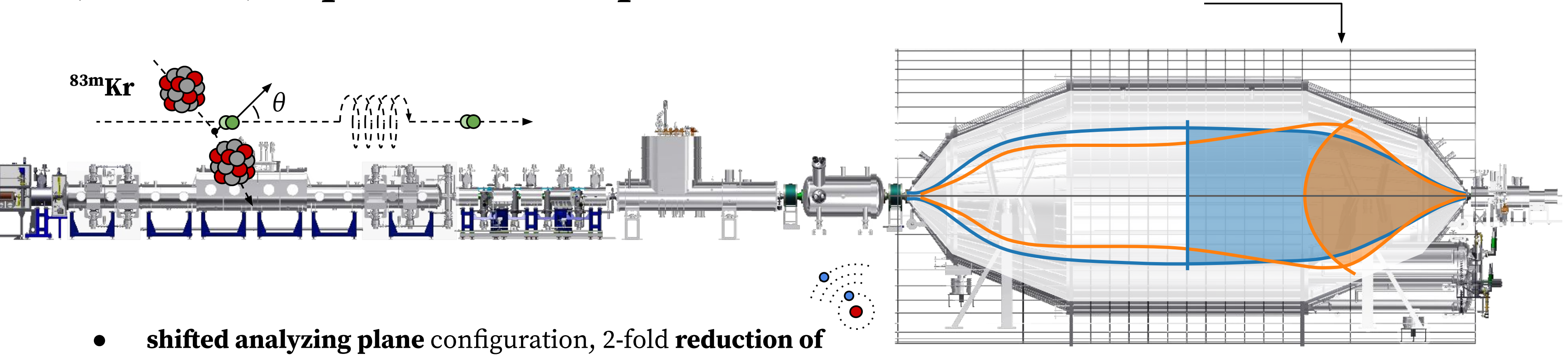
third result, 5 campaigns, 1757 scans,
259 measurement days

continue until end-2025,
1000 measurement days

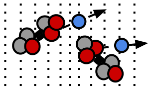
First glance at the latest science runs of the KATRIN neutrino mass experiment using the KaFit analysis package
J. Storek, Poster, Thu 19:00

(Selected) experimental improvements

shifted analyzing plane



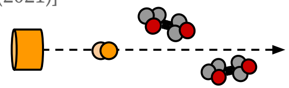
- **shifted analyzing plane** configuration, 2-fold **reduction of background**, inhomogeneous spectrometer fields
  [Lokhov et al., EPJ C 82 (2022)]

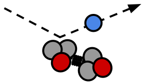


- **^{83m}Kr co-circulation** mode, determine **source potential** and **spectrometer fields**
  [Altenmüller et al., J.Phys.G 47 (2020)]

Measurement of the nuclear transition energies of ^{83m}Kr using the gaseous krypton source of KATRIN
M. Böttcher, Poster, Thu 19:00

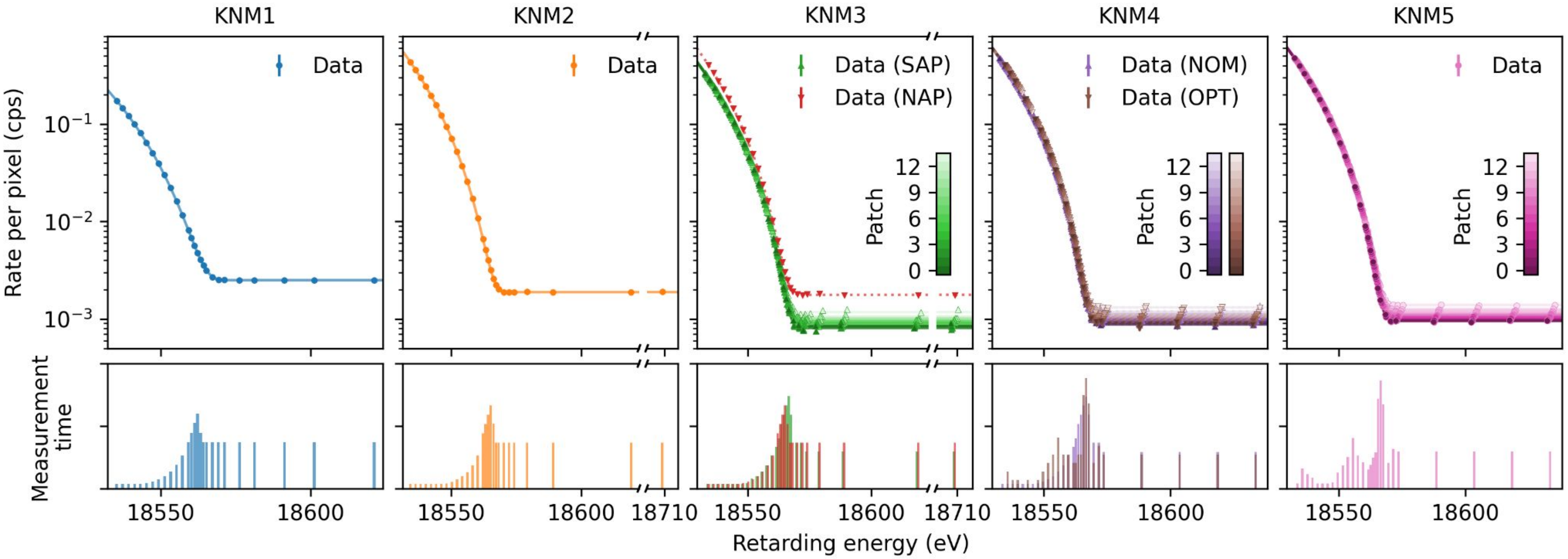
- improved **electron gun**, mono-energetic angular-selective photoelectron source, probe **scattering effects**
  [Aker et al., EPJ C 81 (2021)]



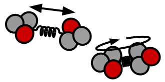


Analysis challenge

- 7 different configurations, 59 spectra, **1609 data points**, **parameter correlations** across datasets



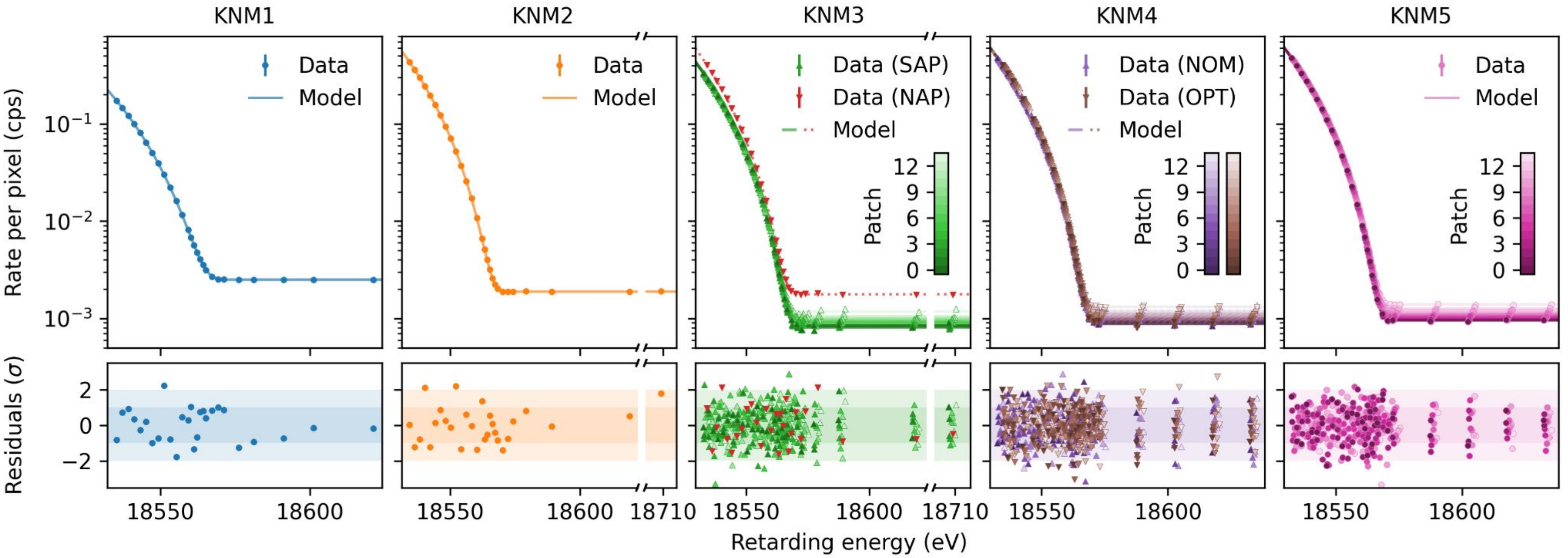
- **2 stage blinding**, simulated data, blinded molecular final states



- fourth campaign split post unblinding, impact ~0.1 eV^2

Fit result

- 7 different configurations, 59 spectra, **1609 data points**, **parameter correlations** across datasets

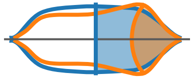


- **2 analysis frameworks**, neural network surrogate [Karl et al., EPJ C 82 (2022)]

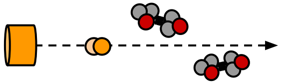
➔ p-value = 0.84, squared neutrino mass best-fit $\boldsymbol{m_\beta^2 = -0.14^{+0.13}_{-0.15}}$ **eV²**

Uncertainty breakdown

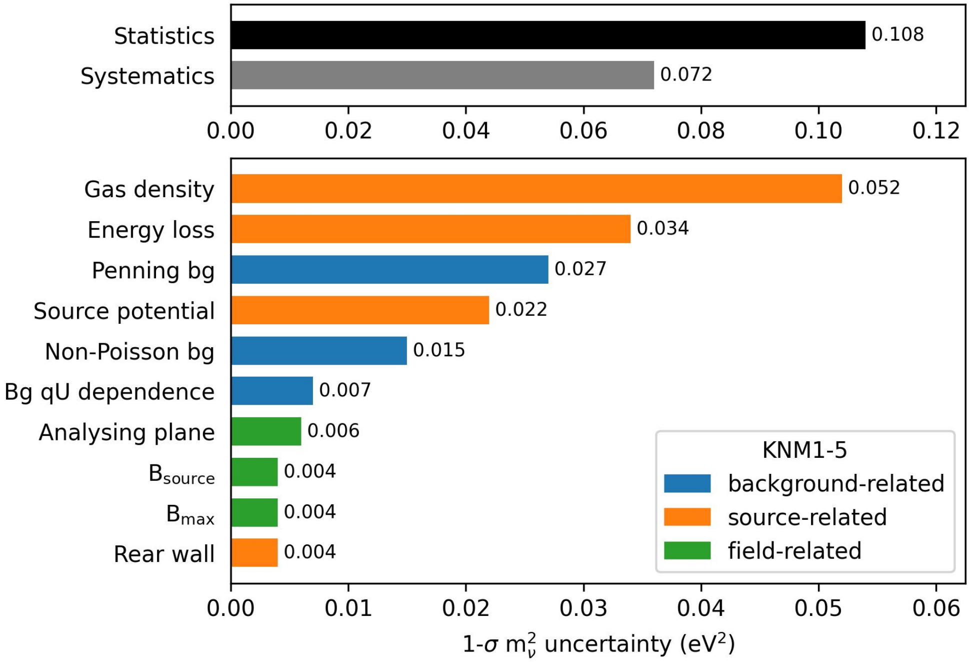
- **6-fold increase in statistics**, 2-fold reduction of background



- **3-fold reduction of systematic uncertainties**, source effects leading



➔ **statistical uncertainty dominates**, improved calibration precision in recent campaigns



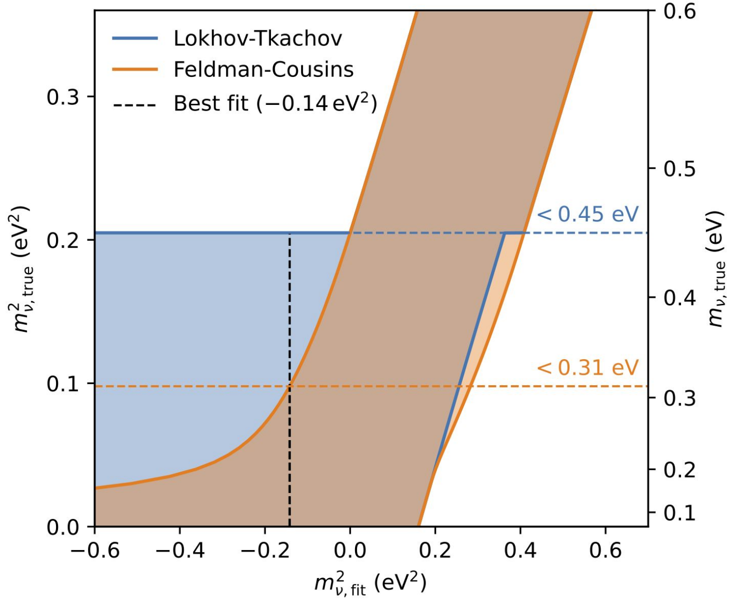
Neutrino mass limit

- new **world-best** direct neutrino mass constraint

  $\boldsymbol{m_\beta}$ **< 0.45 eV** (90% *CL*)

  using **Lokhov-Tkachov** confidence interval construction
  [Lokhov, Tkachov, Phys.Part.Nucl. 46 (2015)]

- Feldman-Cousins construction, $m_\beta < 0.31$ eV (90% *CL*), benefits from negative best-fit



➔ **preprint** available at https://arxiv.org/abs/2406.13516

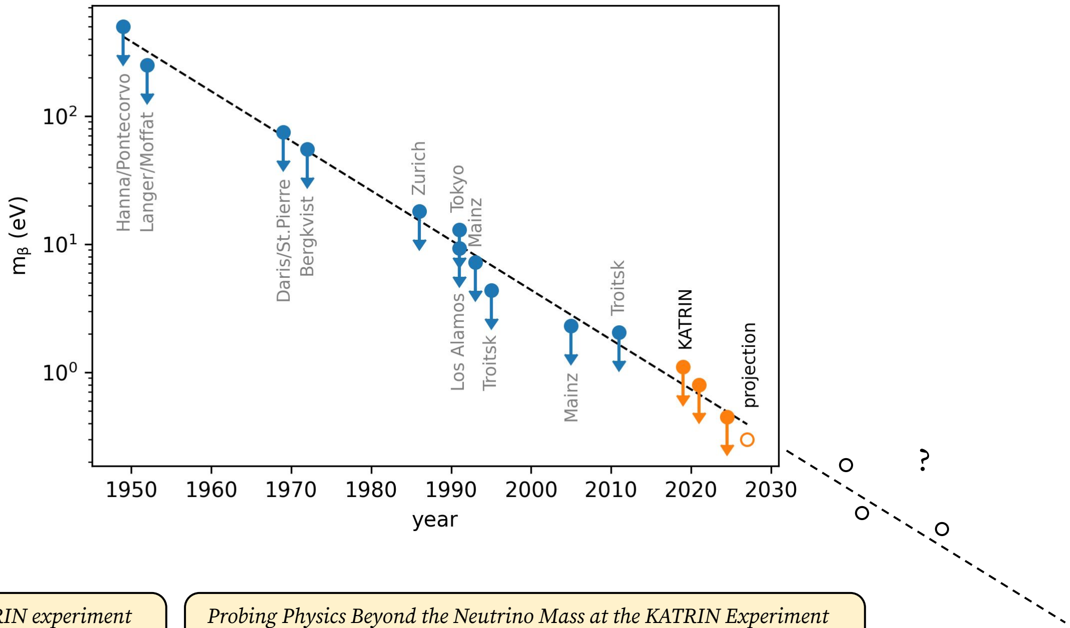
Outlook

- new **world-best** direct neutrino mass constraint

  $\boldsymbol{m_\beta} < \mathbf{0.45\ eV}$ (90% *CL*)

- **data taking ongoing** until end-2025

- rich **non-neutrino mass program**, sterile neutrinos, relic neutrinos, ..
  [Aker et al., PRD 105 (2022); Aker et al., PRL. 129 (2022)]



KATRIN sterile neutrino analysis
C. Köhler, Poster, Thu 19:00

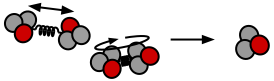
Search for new light bosons with the KATRIN experiment
J. Lauer, Poster, Fri 19:00

Probing Physics Beyond the Neutrino Mass at the KATRIN Experiment
C. Fengler, Talk, Sat 15:15

- **TRISTAN** detector upgrade in 2026, search for **keV-scale sterile neutrinos**
  [Mertens et al., J.Phys.G 46 (2019)]

- beyond 2027, **KATRIN++**, development of **differential** detection and **atomic** tritium technologies

Sensitivity studies for a next-generation neutrino-mass experiment using tritium β-decay
S. Heyns, Poster, Fri 19:00



Backup

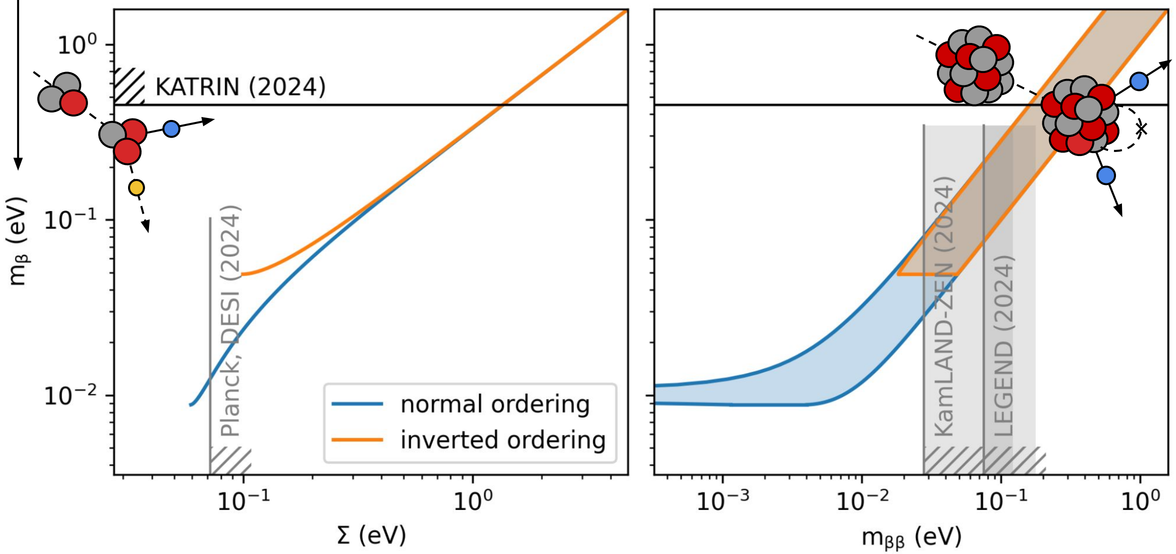
Neutrino mass observables

- β-decay kinematics offers **model-independent laboratory probe** for neutrino mass
- complementary to
  - **cosmology**
  - **0νββ decay**

➔ interplay will allow **model discrimination**

energy conservation

[NuFIT 5.3, nu-fit.org; Adame et al., arXiv:2404.03002; Abe et al., arXiv:2406.11438]



cosmological model

Majorana nature, mass mechanism